

# DOE Energy Storage Systems Program

## Sandia National Laboratories (SNL) Publications

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Report No.	Title	Authors	Date
<a href="#">SAND 2010-0815</a>	<b>Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide</b>	Jim Eyer and Garth Corey	Feb-10
	<p><b>Abstract:</b> This report documents a high-level analysis of the benefit and cost for flywheel energy storage used to provide area regulation for the electricity supply and transmission system in California. Area regulation is an ‘ancillary service’ needed for a reliable and stable regional electricity grid. The analysis was based on results from a demonstration, in California, of flywheel energy storage developed by Beacon Power Corporation (the system’s manufacturer). Demonstrated was flywheel storage systems’ ability to provide ‘rapid-response’ regulation. (Flywheel storage output can be varied much more rapidly than the output from conventional regulation sources, making flywheels more attractive than conventional regulation resources.)</p>		
<a href="#">SAND2009-6457</a>	<b>Benefits from Flywheel Energy Storage for Area Regulation in California — Demonstration Results</b>	Jim Eyer	Oct-09
	<p><b>Abstract:</b> This report documents a high-level analysis of the benefit and cost for flywheel energy storage used to provide area regulation for the electricity supply and transmission system in California. Area regulation is an ‘ancillary service’ needed for a reliable and stable regional electricity grid. The analysis was based on results from a demonstration, in California, of flywheel energy storage developed by Beacon Power Corporation (the system’s manufacturer). Demonstrated was flywheel storage systems’ ability to provide ‘rapid-response’ regulation. (Flywheel storage output can be varied much more rapidly than the output from conventional regulation sources, making flywheels more attractive than conventional regulation resources.)</p>		
<a href="#">SAND2009-4070</a>	<b>Electric Utility Transmission and Distribution Upgrade Deferral Benefits from Modular Electricity Storage</b>	Jim Eyer	Jun-09
	<p><b>Abstract:</b> The work documented in this report was undertaken as part of an ongoing investigation of innovative and potentially attractive value propositions for electricity storage by the United States Department of Energy (DOE) and Sandia National Laboratories (SNL) Electricity Storage Systems (ESS) Program. This study characterizes one especially attractive value proposition for modular electricity storage (MES): electric utility transmission and distribution (T&amp;D) upgrade deferral. The T&amp;D deferral benefit is characterized in detail. Also presented is a generalized framework for estimating the benefit. Other important and complementary (to T&amp;D deferral) elements of possible value propositions involving MES are also characterized.</p>		
<a href="#">SAND2008-8229</a>	<b>Design &amp; Development of a 20-MW Flywheel-based Frequency Regulation Power Plant</b>	Robert Rounds and Georgianne H. Peek	Jan-09
	<p><b>Abstract:</b> This report describes the successful efforts of Beacon Power to design and develop a 20-MW frequency regulation power plant based solely on flywheels. Beacon’s Smart Matrix (Flywheel) Systems regulation power plant, unlike coal or natural gas generators, will not burn fossil fuel or directly produce particulates or other air emissions and will have the ability to ramp up or down in a matter of seconds. The report describes how data from the scaled Beacon system, deployed in California and New York, proved that the flywheel-based systems provided faster responding regulation services in terms of cost-performance and environmental impact. Included in the report is a description of Beacon’s design package for a generic, multi-MW flywheel-based, regulation power plant that allows accurate bids from a design/build contractor and Beacon’s recommendations for site requirements that would ensure the fastest possible construction. The paper concludes with a statement about Beacon’s plans for a lower cost, modular-style, modular-style substation based on the 20-MW design.</p>		

[SAND2008-5583](#)**Selected Test Results from the LiFeBatt Iron Phosphate Li-ion Battery**Thomas D. Hund and  
David T. Ingersoll

Sep-08

**Abstract:** In this paper the performance of the LiFeBatt Li-ion cell was measured using a number of tests including capacity measurements, capacity as a function of temperature, ohmic resistance, spectral impedance, high power partial state of charge (PSOC) pulsed cycling, pulse power measurements, and an over-charge/voltage abuse test. The goal of this work was to evaluate the performance of the iron phosphate Li-ion battery technology for utility applications requiring frequent charges and discharges, such as voltage support, frequency regulation, and wind farm energy smoothing. Test results have indicated that the LiFeBatt battery technology can function up to a 10C1 discharge rate with minimal energy loss compared to the 1 h discharge rate (1C). The utility PSOC cycle test at up to the 4C1 pulse rate completed 8,394 PSOC pulsed cycles with a gradual loss in capacity of 10 to 15% depending on how the capacity loss is calculated. The majority of the capacity loss occurred during the initial 2,000 cycles, so it is projected that the LiFeBatt should PSOC cycle well beyond 8,394 cycles with less than 20% capacity loss. The DC ohmic resistance and AC spectral impedance measurements also indicate that there were only very small changes after cycling. Finally, at a 1C charge rate, the over-charge/voltage abuse resulted in the cell venting electrolyte at 110 °C after 30 minutes and then open-circuiting at 120 °C with no sparks, fire, or voltage across the cell.

[SAND2008-4247](#)**Solar Energy Grid Integration Systems – Energy Storage (SEGIS-ES)**Dan T. Ton, Charles J.  
Hanley, Georgianne H.  
Peek, John D. Boyes

Jul-08

**Abstract:** This paper describes the concept for augmenting the SEGIS Program (an industry-led effort to greatly enhance the utility of distributed PV systems) with energy storage in residential and small commercial applications (SEGIS-ES). The goal of SEGIS-ES is to develop electrical energy storage components and systems specifically designed and optimized for grid-tied PV applications. This report describes the scope of the proposed SEGIS-ES Program and why it will be necessary to integrate energy storage with PV systems as PV-generated energy becomes more prevalent on the nation's utility grid. It also discusses the applications for which energy storage is most suited and for which it will provide the greatest economic and operational benefits to customers and utilities. Included is a detailed summary of the various storage technologies available, comparisons of their relative costs and development status, and a summary of key R&D needs for PV-storage systems. The report concludes with highlights of areas where further PV-specific R&D is needed and offers recommendations about how to proceed with their development.

[SAND2008-0978](#)**Benefit/Cost Framework for Evaluating Modular Energy Storage**Susan M. Schoenung and  
Jim Eyer

Feb-08

**Abstract:** The work documented in this report represents another step in the ongoing investigation of innovative and potentially attractive value propositions for electricity storage by the United States Department of Energy (DOE) and Sandia National Laboratories (SNL) Energy Storage Systems (ESS) Program. This study uses updated cost and performance information for modular energy storage (MES) developed for this study to evaluate four prospective value propositions for MES. The four potentially attractive value propositions are defined by a combination of well-known benefits that are associated with electricity generation, delivery, and use. The value propositions evaluated are: 1) transportable MES for electric utility transmission and distribution (T&D) equipment upgrade deferral and for improving local power quality, each in alternating years, 2) improving local power quality only, in all years, 3) electric utility T&D deferral in year 1, followed by electricity price arbitrage in following years; plus a generation capacity credit in all years, and 4) electric utility end-user cost management during times when peak and critical peak pricing prevail.

[SAND2007-4268](#)**Remote Area Power Supply (RAPS) Load and Resources Profiles**Ndeye Fall, Lauren Giles,  
Brian Marchionini, Edward  
Skolnik

Jul-07

**Abstract:** In 1997, an international team interested in the development of Remote Area Power Supply (RAPS) systems for rural electrification projects around the world was organized by the International Lead Zinc Research Organization (ILZRO) with the support of Sandia National Laboratories (SNL). The team focused on defining load and resource profiles for RAPS systems. They identified single family homes, small communities, and villages as candidates for RAPS applications, and defined several different size/power requirements for each. Based on renewable energy and resource data, the team devised a "strawman" series of load profiles. A RAPS system typically consists of a renewable and/or conventional generator, power conversion equipment, and a battery. The purpose of this report is to present data and information on insolation levels and load requirements for "typical" homes, small communities, and larger villages around the world in order to facilitate the development of robust design practices for RAPS systems, and especially for the storage battery component. These systems could have significant impact on areas of the world that would otherwise not be served by conventional electrical grids.

[SAND2007-4253](#)**Long vs. Short-Term Energy Storage: Sensitivity Analysis**Susan M. Schoenung and  
William Hassenzahl

Jul-07

**Abstract:** This report extends earlier work to characterize long-duration and short-duration energy storage technologies, primarily on the basis of life-cycle cost, and to investigate sensitivities to various input assumptions. Another technology – asymmetric lead-carbon capacitors – has also been added. Energy storage technologies are examined for three application categories – bulk energy storage, distributed generation, and power quality – with significant variations in discharge time and storage capacity. Sensitivity analyses include cost of electricity and natural gas, and system life, which impacts replacement costs and capital carrying charges. Results are presented in terms of annual cost, \$/kW-yr. A major variable affecting system cost is hours of storage available for discharge.

- [SAND2007-3580](#)      **Installation of the First Distributed Energy Storage System (DESS) at American Electric Power (AEP)**      Ali Nourai      Jun-07
- Abstract:** AEP studied the direct and indirect benefits, strengths, and weaknesses of distributed energy storage systems (DESS) and chose to transform its entire utility grid into a system that achieves optimal integration of both central and distributed energy assets. To that end, AEP installed the first NAS battery-based, energy storage system in North America. After one year of operation and testing, AEP has concluded that, although the initial costs of DESS are greater than conventional power solutions, the net benefits justify the AEP decision to create a grid of DESS with intelligent monitoring, communications, and control, in order to enable the utility grid of the future. This report details the site selection, construction, benefits and lessons learned of the first installation, at Chemical Station in North Charleston, WV.
- [SAND2006-6740](#)      **NAS<sup>®</sup> Battery Demonstration at American Electric Power**      Benjamin L. Norris, Jeff Newmiller, Georgianne Peek      Mar-07
- Abstract:** The first U.S. demonstration of the NGK sodium/sulfur battery technology was launched in August 2002 when a prototype system was installed at a commercial office building in Gahanna, Ohio. American Electric Power served as the host utility that provided the office space and technical support throughout the project. The system was used to both reduce demand peaks (peak-shaving operation) and to mitigate grid power disturbances (power quality operation) at the demonstration site. This report documents the results of the demonstration, provides an economic analysis of a commercial sodium/sulfur battery energy storage system at a typical site, and describes a side-by-side demonstration of the capabilities of the sodium/sulfur battery system, a lead-acid battery system, and a flywheel-based energy storage system in a power quality application.
- [SAND2005-7069](#)      **Estimating Electricity Storage Power Rating and Discharge Duration for Utility Transmission and Distribution Deferral**      Jim Eyer, Joe Iannucci, Paul C. Butler      Nov-05
- Abstract:** This report describes a methodology for estimating the power and energy capacities for electricity energy storage systems that can be used to defer costly upgrades to fully overloaded, or nearly overloaded, transmission and distribution (T&D) nodes. This “sizing” methodology may be used to estimate the amount of storage needed so that T&D upgrades may be deferred for one year. The same methodology can also be used to estimate the characteristics of storage needed for subsequent years of deferral.
- [SAND2005-4366](#)      **Final Report on testing of ACONF Technology for the US Coast Guard National Distress Systems**      Garth P. Corey, Jerry W. Ginn, Tom M. Byrd, Leanne M. Storey, Aaron T. Murray, Philip C. Symons      Aug-05
- Abstract:** This report documents the results of a six month test program of an Alternative Configuration (ACONF) power management system design for a typical United States Coast Guard (USCG) National Distress System (NDS) site. The USCG/USDOE funded work was performed at Sandia National Laboratories to evaluate the effect of a Sandia developed battery management technology known as ACONF on the performance of energy storage systems at NDS sites. This report demonstrates the savings of propane gas, and the improvement of battery performance when utilizing the new ACONF designs. The fuel savings and battery performance improvements resulting from ACONF use would be applicable to all current NDS sites in the field. The inherent savings realized when using the ACONF battery management design was found to be significant when compared to battery replacement and propane refueling at the remote NDS sites.
- [SAND2005-0372](#)      **Evaluation of Battery/Microturbine Hybrid Energy Storage Technologies at the University of Maryland**      Mindi Farber de Anda, Ndeye K. Fall      Mar-05
- Abstract:** This study describes the technical and economic benefits derived from adding an energy storage component to an existing building cooling, heating, and power system that uses microturbine generation to augment utility-provided power. Three different types of battery energy storage were evaluated: flooded lead-acid, valve-regulated lead-acid, and zinc/bromine. Additionally, the economic advantages of hybrid generation/storage systems were evaluated for a representative range of utility tariffs. The analysis was done using the Distributed Energy Technology Simulator developed for the Energy Storage Systems Program at Sandia National Laboratories by Energetics, Inc. The study was sponsored by the U.S. DOE Energy Storage Systems Program through Sandia National Laboratories and was performed in coordination with the University of Maryland’s Center for Environmental Energy Engineering

- [SAND2004-6177](#) **Energy Storage Benefits and Market Analysis Handbook** James M. Eyer, Joseph J. Iannucci, Garth P. Corey Dec-04
- Abstract:** This Guide describes a high level, technology-neutral framework for assessing potential benefits from and economic market potential for energy storage used for electric utility-related applications. In the United States use of electricity storage to support and optimize transmission and distribution (T&D) services has been limited due to high storage system cost and by limited experience with storage system design and operation. Recent improvement of energy storage and power electronics technologies, coupled with changes in the electricity marketplace, indicate an era of expanding opportunity for electricity storage as a cost-effective electric resource. Some recent developments (in no particular order) that drive the opportunity include: 1) states' adoption of the renewables portfolio standard (RPS), which may increase use of renewable generation with intermittent output, 2) financial risk leading to limited investment in new transmission capacity, coupled with increasing congestion on some transmission lines, 3) regional peaking generation capacity constraints, and 4) increasing emphasis on locational marginal pricing (LMP).
- [SAND2004-0914](#) **Reliability of Valve-Regulated Lead-Acid Batteries for Stationary Applications** Mindi Farber DeAnda, Jennifer Miller, Patrick Moseley, Paul Butler Mar-04
- Abstract:** A survey has been carried out to quantify the performance and life of over 700,000 valveregulated lead-acid (VRLA) cells, which have been or are being used in stationary applications across the United States. The findings derived from this study have not identified any fundamental flaws of VRLA battery technology. There is evidence that some cell designs are more successful in float duty than others. A significant number of the VRLA cells covered by the survey were found to have provided satisfactory performance.
- [SAND2004-0372](#) **Evaluation of Battery/Microturbine Hybrid Energy Storage Technologies at the University of Maryland** Mindi Farber DeAnda, Ndeye K. Fall Oct-04
- Abstract:** This study describes the technical and economic benefits derived from adding an energy storage component to an existing building cooling, heating, and power system that uses microturbine generation to augment utility-provided power. Three different types of battery energy storage were evaluated: flooded lead-acid, valve-regulated lead-acid, and zinc/bromine. Additionally, the economic advantages of hybrid generation/storage systems were evaluated for a representative range of utility tariffs. The analysis was done using the Distributed Energy Technology Simulator developed for the Energy Storage Systems Program at Sandia National Laboratories by Energetics, Inc. The study was sponsored by the U.S. DOE Energy Storage Systems Program through Sandia National Laboratories and was performed in coordination with the University of Maryland's Center for Environmental Energy Engineering.
- [SAND2003-2783](#) **Long vs. Short-Term Energy Storage Technologies Analysis: A Life Cycle Cost Study.** Susan M. Schoenung, William V. Hassenzehl, Aug-03
- Abstract:** This report extends an earlier characterization of long-duration and short-duration energy storage technologies to include life-cycle cost analysis. Energy storage technologies were examined for three application categories—bulk energy storage, distributed generation, and power quality—with significant variations in discharge time and storage capacity. More than 20 different technologies were considered and figures of merit were investigated including capital cost, operation and maintenance, efficiency, parasitic losses, and replacement costs. Results are presented in terms of levelized annual cost, \$/kW-yr. The cost of delivered energy, cents/kWh, is also presented for some cases. The major study variable was the duration of storage available for discharge.
- [SAND2003-2546](#) **Innovative Applications of Energy Storage in a Restructured Electricity Marketplace Phase III Final Report** Joe Iannucci, Jim Eyer, Bill Erdman Mar-05
- Abstract:** This report describes Phase III of a project entitled Innovative Applications of Energy Storage in a Restructured Electricity Marketplace. For this study, the authors assumed that it is feasible to operate an energy storage plant simultaneously for two primary applications: 1) energy arbitrage, i.e., buy-low-sell-high, and 2) to reduce peak loads in utility "hot spots" such that the utility can defer their need to upgrade transmission and distribution (T&D) equipment. The benefits from the arbitrage plus T&D deferral applications were estimated for five cases based on the specific requirements of two large utilities operating in the Eastern U.S. A number of parameters were estimated for the storage plant ratings required to serve the combined application: power output (capacity) and energy discharge duration (energy storage). In addition to estimating the various financial expenditures and the value of electricity that could be realized in the marketplace, technical characteristics required for grid-connected distributed energy storage used for capacity deferral were also explored.

- [SAND2003-0362](#) **Innovative Business Cases for Energy Storage in a Restructured Electricity Marketplace** J. Iannucci, J. Eyer, and Paul C. Butler Feb-03
- Abstract:** This report describes the second phase of a project entitled Innovative Business Cases for Energy Storage in a Restructured Electricity Marketplace. During part one of the effort, nine "Stretch Scenarios" were identified. They represented innovative and potentially significant uses of electric energy storage. Based on their potential to significantly impact the overall energy marketplace, the five most compelling scenarios were identified. From these scenarios, five specific "Storage Market Opportunities" (SMOs) were chosen for an in-depth evaluation in this phase. The authors conclude that some combination of the Power Cost Volatility and the T&D Benefits SMOs would be the most compelling for further investigation. Specifically, a combination of benefits (energy, capacity, power quality and reliability enhancement) achievable using energy storage systems for high value T&D applications, in regions with high power cost volatility, makes storage very competitive for about 24 GW and 120 GWh during the years of 2001 and 2010.
- [SAND2002-4084](#) **Technical and Economic Feasibility Of Applying Used EV Batteries in Stationary Applications.** Erin Cready, John Lippert, Josh Pihl, Irwin Weinstock, Philip C. Symons, Rudy Jungst Mar-03
- Abstract:** The technical and economic feasibility of applying used electric vehicle (EV) batteries in stationary applications was evaluated in this study. In addition to identifying possible barriers to EV battery reuse, steps needed to prepare the used EV batteries for a second application were also considered. Costs of acquiring, testing, and reconfiguring the used EV batteries were estimated. Eight potential stationary applications were identified and described in terms of power, energy, and duty cycle requirements. Costs for assembly and operation of battery energy storage systems to meet the requirements of these stationary applications were also estimated by extrapolating available data on existing systems. The calculated life cycle cost of a battery energy storage system designed for each application was then compared to the expected economic benefit to determine the economic feasibility. Four of the eight applications were found to be at least possible candidates for economically viable reuse of EV batteries. These were transmission support, light commercial load following, residential load following, and distributed node telecommunications backup power. There were no major technical barriers found, however further study is recommended to better characterize the performance and life of used EV batteries before design and testing of prototype battery systems.
- [SAND2002-3201J](#) **Correlation of Arrhenius Behavior in Power and Capacity Fades with Cell Impedance and Heat Generation in Cylindrical Lithium-ion Cells** Bor Yann Liaw, Emanuel P. Roth, Rudolph G. Jungst, Ganesan Nagasubramanian, Herbert L. Case, Daniel H. Doughty Aug-02
- Abstract:** A series of cylindrical 18650 lithium-ion cells with an MAG-10 I 1.2 M LiPF<sub>6</sub> EC (ethylene carbonate): EMC (ethyl methyl carbonate) (w/w=3:7) 1 Li<sub>1-x</sub>Ni<sub>x</sub>Co<sub>0.5</sub>Al<sub>0.5</sub>O<sub>2</sub> configuration were made and tested for power-assist hybrid electric vehicle (HEV) applications under various aging conditions of temperature and state-of-charge (SOC). The cells were intermittently characterized for changes in power capability, rate capacity, and impedance as aging progressed. The changes of these properties with temperature, as depicted by Arrhenius equations, were analyzed. We found that the degradation in power and capacity fade seems to relate to the impedance increase in the cell. The degradation follows a multi-stage process. The initial stage of degradation has an activation energy on the order of 50-55 kJ/mol, as derived from power fade and C1 capacity fade measured at C/1 rate. In addition, microcalorimetry was performed on two separate unaged cells at 80% SOC at various temperatures to measure static heat generation in the cells. We found that the static heat generation has an activation energy on the order of 48-55 kJ/mol, similar to those derived from power and C1 capacity fade. The correspondence in the magnitude of the activation energy suggests that the power and C1 capacity fades were related to the changes of the impedance in the cells, most likely via the same fading mechanism. The fading mechanism seemed to be related to the static heat generation of the cell.
- [SAND2002-1532J](#) **Battcon 2002: A Perspective** Garth P. Corey, Jack Mack May-02
- Abstract:** (Not available at this time)
- [SAND2002-1314](#) **Energy Storage Opportunities Analysis Phase II Final Report** P. C. Butler May-02
- Abstract:** This study on the opportunities for energy storage technologies determined electric utility application requirements, assessed the suitability of a variety of storage technologies to meet the requirements, and reviewed the compatibility of technologies to satisfy multiple applications in individual installations. The study is called "Opportunities Analysis" because it identified the most promising opportunities for the implementation of energy storage technologies in stationary applications. The study was sponsored by the U.S. DOE Energy Storage Systems Program through Sandia National Laboratories and was performed in coordination with industry experts from utilities, manufacturers, and research organizations. This Phase II report updates the Phase I analysis performed in 1994.



[SAND2002-0751](#)**Boulder City Battery Energy Storage Feasibility Study**Garth P. Corey, Larry E.  
Stoddard, Ryan M.  
Kerschen

Mar-02

**Abstract:** Sandia National Laboratories and Black & Veatch, Inc., conducted a system feasibility study to examine options for placing at Boulder City, Nevada an advanced energy storage system that can store off-peak, hydroelectric generated electricity for use during on-peak times. It evaluated the feasibility and economic impact of an energy storage demonstration project currently under consideration for the Municipal Utility Power Company for the City of Boulder City. The study included evaluations of a proposed site and appropriate advanced battery technologies, pre-conceptual design, artist's conceptions, seasonal electricity load profiles, cost estimates for the battery storage system plus site development and operating costs, and an economic evaluation of the site's payback potential. The study concluded that the Boulder City site is a viable candidate for a Demonstration Unit of an advanced Battery Energy Storage System (BESS) utilizing either Sodium Sulfur, Vanadium Redox, or Zinc Bromine and Regenesys® technologies and that it would provide a net value to the City of Boulder.

[SAND2002-4084](#)**Technical and Economic Feasibility of Applying Used EV Batteries in Stationary Applications.**Erin Cready, John Lippert,  
Josh Pihl, Irwin Weinstock,  
Phillip Symons, Rudolph  
Jungst

Mar-02

**Abstract:** The technical and economic feasibility of applying used electric vehicle (EV) batteries in stationary applications was evaluated in this study. In addition to identifying possible barriers to EV battery reuse, steps needed to prepare the used EV batteries for a second application were also considered. Costs of acquiring, testing, and reconfiguring the used EV batteries were estimated. Eight potential stationary applications were identified and described in terms of power, energy, and duty cycle requirements. Costs for assembly and operation of battery energy storage systems to meet the requirements of these stationary applications were also estimated by extrapolating available data on existing systems. The calculated life cycle cost of a battery energy storage system designed for each application was then compared to the expected economic benefit to determine the economic feasibility. Four of the eight applications were found to be at least possible candidates for economically viable reuse of EV batteries. These were transmission support, light commercial load following, residential load following, and distributed node telecommunications backup power. There were no major technical barriers found, however further study is recommended to better characterize the performance and life of used EV batteries before design and testing of prototype battery systems.

[SAND2001-3188](#)**Development of the Capabilities to Analyze the Vulnerability of Bulk Power Systems**David Knusman, David  
Tobinson, Salvador  
Rodriguez, Rudolph Jungst,  
Angel Urbina, Thomas  
Paez, Satish Ranade

Oct-01

**Abstract:** The electrical grids of North America are an extremely large and complex set of interconnected networks vital to the economic lifeblood and safety of more than 380 million people. These networks are dynamic and constantly changing systems whose operation is vulnerable to significant disruptions due to evolving energy policies as well as from natural and man-made sources. The President's Commission on Critical Infrastructure Protection has identified electric power as a critical infrastructure sector. The 1996 blackouts of the western power system demonstrated the weaknesses of the current power grid reliability analysis tools and highlighted the need for improved techniques to deal with the uncertainties associated with the operation of a bulk power network. An alternative approach involves probabilistic load-flow characterization and is closely related to the analysis methods being developed as part of the nuclear weapon system stockpile surveillance program. Integration of the new probabilistic load-flow analysis techniques and sensitivity analysis methods will provide the tools necessary to statistically characterize the load shedding at each major bus in a very large bulk power system. By probabilistically characterizing the amount of load shed at each network node and then relating this measure to the sensitivity of the grid to failure of this node, the reliability of the grid can be understood more thoroughly. The major objective of this effort was the integration of traditional load-flow analysis packages, advanced optimization methods, and state-of-the-art uncertainty analysis techniques. In parallel with this effort, we addressed issues associated with short-term energy storage devices (e.g., batteries) that might impact the overall reliability of the bulk power system. It was anticipated that a significant impediment to integrating these various tools and techniques was the size of bulk power systems that could be analyzed with this complex suite of tools. Therefore, a secondary objective was the implementation of all software analysis tools on the massively parallel computer systems at Sandia National Laboratories. These risk-based analytical tools can be used for short-term (daily) vulnerability assessment and long-term (yearly) planning for improved network security.

[SAND2001-1110J](#)**Performance of Valve-Regulated Lead-Acid Batteries in Real-World Stationary Applications: Utility Installations**

Paul C. Butler, Jennifer Dunleavey, Mindi Farber-Deanda, Patrick T. Moseley

Apr-01

**Abstract:** The electrical grids of North America are an extremely large and complex set of interconnected networks vital to the economic lifeblood and safety of more than 380 million people. These networks are dynamic and constantly changing systems whose operation is vulnerable to significant disruptions due to evolving energy policies as well as from natural and man-made sources. The President's Commission on Critical Infrastructure Protection has identified electric power as a critical infrastructure sector. The 1996 blackouts of the western power system demonstrated the weaknesses of the current power grid reliability analysis tools and highlighted the need for improved techniques to deal with the uncertainties associated with the operation of a bulk power network. An alternative approach involves probabilistic load-flow characterization and is closely related to the analysis methods being developed as part of the nuclear weapon system stockpile surveillance program. Integration of the new probabilistic load-flow analysis techniques and sensitivity analysis methods will provide the tools necessary to statistically characterize the load shedding at each major bus in a very large bulk power system. By probabilistically characterizing the amount of load shed at each network node and then relating this measure to the sensitivity of the grid to failure of this node, the reliability of the grid can be understood more thoroughly. The major objective of this effort was the integration of traditional load-flow analysis packages, advanced optimization methods, and state-of-the-art uncertainty analysis techniques. In parallel with this effort, we addressed issues associated with short-term energy storage devices (e.g., batteries) that might impact the overall reliability of the bulk power system. It was anticipated that a significant impediment to integrating these various tools and techniques was the size of bulk power systems that could be analyzed with this complex suite of tools. Therefore, a secondary objective was the implementation of all software analysis tools on the massively parallel computer systems at Sandia National Laboratories. These risk-based analytical tools can be used for short-term (daily) vulnerability assessment and long-term (yearly) planning for improved network security.

[SAND2001-0765](#)**Characteristics and Technologies for Long vs. Short-Term Energy Storage**

S.M. Schoenung

Mar-01

**Abstract:** This report describes the results of a study on stationary energy storage technologies for a range of applications that were categorized according to storage duration (discharge time): long or short. The study was funded by the U.S. Department of Energy through the Energy Storage Systems Program. A wide variety of storage technologies were analyzed according to performance capabilities, cost projects, and readiness to serve these many applications, and the advantages and disadvantages of each are presented.

[SAND2000-1004](#)**Operating Environment and Functional Requirements for Intelligent Distributed Control in the Electric Power Grid**

Douglas C. Smathers, Abbas A. Akhil

Mar-01

**Abstract:** The restructuring of the U.S. power industry will surely lead to a greater dependence on computers and communications to allow appropriate information sharing for management and control of the power grid. This report describes the operating environment for system operations that control the bulk power system as it exists today including the role NERC plays in this process. Some high-level functional requirements for new approaches to control of the grid are listed followed by a description of the next research steps that are needed to identify specific information management functions.

[SAND2000-3083](#)**Advanced Battery Readiness Ad Hoc Working Group Meeting: Reclamation/Recycle Sub-Working Group Supplement and Update**

Rudolph G. Jungst

Dec-00

**Abstract:** An update on the California ZEV program was presented. The most recent program review occurred in September 2000 but was not a regulatory review. This means that no changes were made to the program at that time. California rules for handling hazardous waste were also discussed. An emergency Universal Waste Rule has been adopted on an interim basis in California in order to provide a single standard. Information on recycling and life cycle costs was presented for the nickel/metal hydride and lithium-ion battery systems. For AB2 type Ni/MH batteries, the value is in the nickel and in the metal hydride alloy. In the Li-ion case, the cathode is responsible for most of the value, unless a manganese oxide cathode is used. Prices and market trends for some of the more important battery materials were reviewed. Nickel prices have recovered from the depressed levels of 1998, and have been relatively stable over the past year. Commodity recycling flow diagrams are being developed by the US Geological Survey for several metals, including nickel. A facility in Argentina that was scheduled to open last year for the production of lithium from a brine source is now permanently closed. However, lithium prices have remained relatively stable. The operation of the INMETCO battery recycling capability was reviewed. Expansion of the cadmium recovery facility at INMETCO has increased capacity by 75% for that material. The complex set of factors that governs recycling economics was discussed. Lithium Technology Corporation and Pacific Lithium Ltd. will merge early next year. A membrane process developed by Pacific Lithium to purify lithium recovered from scrap batteries was discussed. The process currently operates on a laboratory scale in a batch mode, and an energy study projects that it will be cost effective. A new project by GM Ovonic to field used NiMH batteries from EVs for rural electrification in Oaxaca Mexico was described. This is primarily seen as a way to mitigate the high initial cost of this battery system. The entire Sub-Working Group discussed the status and future needs for comprehensive recycling of nickel/metal hydride and Li-ion batteries.

<a href="#">SAND2000-2065J</a>	<b>Summary of Electrical Test Results for VRLA Batteries</b>	Crow, James Terry; Francis, Imelda; Butler, Paul Charles	Aug-00
	<b>Abstract:</b> Sandia National Laboratories conducts the Energy Storage Systems (ESS) Program for the U.S. Department of Energy (DOE). The goal of this program is to collaborate with industry in developing cost-effective electric energy storage systems for many high-value stationary applications. Under the auspices of the ESS Program, electrical tests were performed on two VRLA batteries to compare effects of improvements, evaluate their applicability to stationary applications, and to determine their service lives. One battery represented a baseline design, and the other an improved design resulting from a development project. The hVO 9-cell, 1050-to 1200- Ah at C/8 batteries were tested over a 7-year period using primarily a 100%/ODOD, and approximately a C/8 discharge regime. A variety of charge profiles were investigated and characterized. Both batteries reached end-of-life after several hundred cycles. This paper will describe these results, and overall life data and comparison information will be summarized.		
<a href="#">SAND2000-1734</a>	<b>Development of an Abuse Tolerance Test Protocol with Continuous Gas Monitoring</b>	Chris C Crafts, Theodore Borek III, Rudolph G Jungst, Daniel H Dougherty, Curtis D Mowry	Jul-00
	<b>Abstract:</b> (Not available at this time)		
<a href="#">SAND2000-1733</a>	<b>Life Cycle Testing of High Power 18650 Lithium-ion Cells</b>	Terry U., David Ingersoll, Chet Motloch, Vince Battaglia, Ira Bloom, Harold Haskins	Jul-00
	<b>Abstract:</b> (Not available at this time)		
<a href="#">SAND2000-1730</a>	<b>Diagnostic Techniques: Gas/Electrolyte/Cell Component Analysis</b>	Rudolph G Jungst, Ganesan Nagasubramanian, Chris C Crafts, Theodore Borek III	Jul-00
	<b>Abstract:</b> (Not available at this time)		
<a href="#">SAND2000-1550</a>	<b>Energy Storage Concepts for a Restructured Electric Utility Industry</b>	Joe Iannucci and Susan. Schoenung	Jul-00
	<b>Abstract:</b> The electric utility industry in the United States is being restructured and is now evolving from a regulated monopoly to a partially competitive, partially regulated group of electricity providers. This report outlines a wide range of innovative ways in which energy storage could be advantageously used in all aspects of this electric supply system of the future, including customer-sited storage. Nine scenarios that consider the use of storage in the restructured utility industry are described. From these scenarios, four themes for guiding the economic and technical application of energy storage are presented		
<a href="#">SAND2000-1317</a>	<b>Energy Storage Systems Program Report for FY99</b>	John. D. Boyes	Jun-00
	<b>Abstract:</b> Sandia National Laboratories, New Mexico, conducts the Energy Storage Systems Program, which is sponsored by the U.S. Department of Energy's Office of Power Technologies. The goal of this program is to develop cost-effective electric energy storage for many high-value stationary applications in collaboration with academia and industry. Sandia National Laboratories is responsible for the engineering analyses, contracted development, and testing of energy storage components and systems. This report details the technical achievements realized during fiscal year 1999.		
<a href="#">SAND2000-0893</a>	<b>Zinc/Bromine Batteries</b>	Paul Butler, Phillip Eidler, Patrick Grimes, Sandra Klassen, Ronald Miles	Apr-00
	<b>Abstract:</b> (Not available at this time)		
<a href="#">SAND2000-0899</a>	<b>Diagnostic Techniques: Gas/Electrolyte/Cell Component Analysis</b>	Rudolph Jungst, Ganesan Nagasubramanian, Chris C Crafts	Mar-00
	<b>Abstract:</b> (Not available at this time)		



- [SAND99-2691](#)      **Development of Zinc/Bromine Batteries for Load-Leveling Applications: Phase 2 Final Report**      N. C. Clark, P. Eidler, and P. Lex      Oct-99
- Abstract:** This report documents Phase 2 of a project to design, develop, and test a zinc/bromine battery technology for use in utility energy storage applications. The project was co-funded by the U.S. Department of Energy Office of Power Technologies through Sandia National Laboratories. The viability of the zinc/bromine technology was demonstrated in Phase 1. In Phase 2, the technology developed during Phase 1 was scaled up to a size appropriate for the application. Batteries were increased in size from 8-cell, 1170-cm<sup>2</sup> cell stacks (Phase 1) to 8- and then 60-cell, 2500-cm<sup>2</sup> cell stacks in this phase. The 2500-cm<sup>2</sup> series battery stacks were developed as the building block for large utility battery systems. Core technology research on electrolyte and separator materials and on manufacturing techniques, which began in Phase 1, continued to be investigated during Phase 2. Finally, the end product of this project was a 100-kWh prototype battery system to be installed and tested at an electric utility.
- [SAND99-2570](#)      **Utility Test Results of a 2-Megawatt, 10-Second Reserve-Power System**      B. L. Norris and G. J. Ball,      Oct-99
- Abstract:** This report documents the 1996 evaluation by Pacific Gas and Electric Company of an advanced reserve-power system capable of supporting 2 MW of load for 10 seconds. The system, developed under a DOE Cooperative Agreement with AC Battery Corporation of East Troy, Wisconsin, contains battery storage that enables industrial facilities to "ride through" momentary outages. The evaluation consisted of tests of system performance using a wide variety of load types and operating conditions. The tests, which included simulated utility outages and voltage sags, demonstrated that the system could provide continuous power during utility outages and other disturbances and that it was compatible with a variety of load types found at industrial customer sites.
- [SAND99-2232](#)      **Lessons Learned from the Puerto Rico Battery Energy Storage System**      M. Farber De Anda, J. D. Boyes, and W. Torres      Sep-99
- Abstract:** The Puerto Rico Electric Power Authority (PREPA) installed a distributed battery energy storage system in 1994 at a substation near San Juan, Puerto Rico. It was patterned after two other large energy storage systems operated by electric utilities in California and Germany. The U.S. Department of Energy (DOE) Energy Storage Systems Program at Sandia National Laboratories has followed the progress of all stages of the project since its inception. It directly supported the critical battery room cooling system design by conducting laboratory thermal testing of a scale model of the battery under simulated operating conditions. The Puerto Rico facility is at present the largest operating battery storage system in the world and is successfully providing frequency control, voltage regulation, and spinning reserve to the Caribbean island. The system further proved its usefulness to the PREPA network in the fall of 1998 in the aftermath of Hurricane Georges. The owner-operator, PREPA, and the architect/engineer, vendors, and contractors learned many valuable lessons during all phases of project development and operation. In documenting these lessons, this report will help PREPA and other utilities in planning to build large energy storage systems
- [SAND99-1853](#)      **Development of Zinc/Bromine Batteries for Load-Leveling Applications: Phase 1 Final Report**      P. Eidler      Jul-99
- Abstract:** Phase 1 of the Zinc/Bromine Load-leveling Development contract (No. 40-8965) advanced zinc/bromine battery technology demonstrates that it would be appropriate for electric utilities to establish stationary energy-storage facilities. Performances of 8-cell and 100-cell laboratory batteries met or exceeded criteria that were established to address concerns observed in previous development efforts. A battery stack that remained leak free was assembled. This report details the results of the Phase 1 efforts. A leak-free battery stack was developed, and a solid technology base for larger battery designs was established. Also, using a proprietary model from Johnson Controls Battery Group, Inc., modeling to improve the integrity and performance of battery stacks was performed.
- [SAND99-1483](#)      **Performance and Design Analysis of a 250-kW, Grid-Connected Battery Energy Storage System**      B. L. Norris and G. J. Ball      Jun-99
- Abstract:** This report documents the assessment of performance and design of a 250-kW prototype battery energy storage system developed by Omnion Power Engineering Company and tested by Pacific Gas and Electric Company, both in collaboration with Sandia National Laboratories. The assessment included system performance, operator interface, and reliability. The report also discusses how to detect failed battery strings with strategically located voltage measurements.
- [SAND99-0883](#)      **Energy Storage Systems Program Report for FY98**      P. C. Butler      Apr-99
- Abstract:** Sandia National Laboratories, New Mexico, conducts the Energy Storage Systems Program, which is sponsored by the U.S. Department of Energy's Office of Power Technologies. The goal of this program is to collaborate with industry in developing cost-effective electric energy storage systems for many high-value stationary applications. Sandia National Laboratories is responsible for the engineering analyses, contracted development, and testing of energy storage components and systems. This report details the technical achievements realized during fiscal year 1998.

- [SAND98-2019](#)      **Summary of State-of-the-Art Power Conversion Systems for Energy Storage Applications**      S. Atcitty, S. Ranade, A. Gray-Fenner      Sep-98
- Abstract:** The power conversion system (PCS) is a vital part of many energy storage systems. It serves as the interface between the storage device, an energy source, and an AC load. This report summarizes the results of an extensive study of state-of-the-art power conversion systems used for energy storage applications. The purpose of the study was to investigate the potential for cost reduction and performance improvement in these power conversion systems and to provide recommendations for future research and development. This report provides an overview of PCS technology, a description of several state-of-the-art power conversion systems and how they are used in specific applications, a summary of four basic configurations for the power conversion systems used in energy storage applications, a discussion of PCS costs and potential cost reductions, a summary of the standards and codes relevant to the technology, and recommendations for future research and development.
- [SAND98-1905](#)      **Battery Energy Storage Systems Life Cycle Costs Case Studies**      S. Swaminathan, N. F. Miller, and R. K. Sen      Aug-98
- Abstract:** This report presents a comparison of life cycle costs between battery energy storage systems and alternative mature technologies that could serve the same utility-scale applications. Two of the battery energy storage systems presented in this report are located on the supply side, providing spinning reserve and system stability benefits. These systems are compared with the alternative technologies of oil-fired combustion turbines and diesel generators. The other two battery energy storage systems are located on the demand side for use in power quality applications. These are compared with available uninterruptible power supply technologies.
- [SAND98-1904](#)      **Analysis of the Value of Battery Energy Storage with Wind & Photovoltaic Generation to the Sacramento Municipal Utility District**      H. Zaininger      Aug-98
- Abstract:** The U.S. Department of Energy's Energy Storage Systems Program at Sandia National Laboratories funded a study to determine the economic and operational value of battery storage to wind and photovoltaic technologies on the Sacramento Municipal Utility District system. This report presents the performance predictions and preliminary benefit-cost results for battery storage added to the Solano wind plant and the Hedge photovoltaic plant.
- [SAND98-1733](#)      **Energy Storage Systems Program Report for FY97**      P. C. Butler      Aug-98
- Abstract:** Sandia National Laboratories, New Mexico, conducts the Energy Storage Systems Program, which is sponsored by the U.S. Department of Energy's Office of Utility Technologies. The goal of this program is to collaborate with industry in developing cost-effective electric energy storage systems for many high-value stationary applications. Sandia National Laboratories is responsible for the engineering analyses, contracted development, and testing of energy storage components and systems. This report details the technical achievements realized during fiscal year 1997.
- [SAND97-1276](#)      **Final Report on the Development of a 250-kW Modular, Factory-Assembled Battery Energy Storage System**      G. P. Corey, W. Nerbun, and D. Porter      Aug-98
- Abstract:** A power management energy storage system was developed for stationary applications such as peak shaving, voltage regulation, and spinning reserve. Project activities included design, manufacture, factory testing, and field installation. The major features that characterize the development are the modularity of the product, its transportability, the power conversion method that aggregates power on the AC side of the converter, and the use of commonly employed technology for system components.
- [SAND98-1513](#)      **Review of Power Quality Applications of Energy Storage Systems**      S. Swaminathan and R. K. Sen      Jul-98
- Abstract:** Under the sponsorship of the U.S. Department of Energy (DOE) Office of Utility Technologies, the Energy Storage Systems Analysis and Development Department at Sandia National Laboratories contracted Sentech, Inc., to assess the impact of power quality problems on the electricity supply system. This report contains the results of several studies that have identified the cost of power quality events for electricity users and providers. The large annual cost of poor power quality represents a national inefficiency and is reflected in the cost of goods sold, reducing U.S. competitiveness. The Energy Storage Systems (ESS) Program takes the position that mitigation merits the attention of not only the DOE but affected industries as well as businesses capable of assisting in developing solutions to these problems. This study represents the preliminary stages of an overall strategy by the ESS Program to understand the magnitude of these problems so as to begin the process of engaging industry partners in developing solutions.
- [SAND98-0591](#)      **Renewable Generation & Storage Project Industry & Laboratory Recommendations**      N.C. Clark, P. Butler, C.P. Cameron      Mar-98
- Abstract:** The United States Department of Energy Office of Utility Technologies is planning a series of related projects that will seek to improve the integration of renewable energy generation with energy storage in modular systems. The Energy Storage Systems Program and the Photovoltaics Program at Sandia National Laboratories conducted meetings to solicit industry guidance and to create a set of recommendations for the proposed projects. Five possible projects were identified and a "three-pronged" approach was recommended. The recommended approach includes preparing a storage technology handbook, analyzing data from currently fielded systems, and defining future user needs and application requirements.

<a href="#">SAND97-2700</a>	<b>Renewable Generation &amp; Storage Project Industry &amp; Laboratory Recommendations</b>	N. C. Clark, P. C. Butler, and C.P. Cameron	Mar-98
	<b>Abstract:</b> Under the sponsorship of the U.S. Department of Energy (DOE) Office of Utility Technologies, the Energy Storage Systems Analysis and Development Department at Sandia National Laboratories conducted a series of dialogs with industry regarding the uses and value of storage in stationary applications. The dialogs consisted of meetings with industry executives in which Energy Storage Systems (ESS) Program management solicited input regarding expected changes in the electric utility industry and the long-term research and development in storage technologies and systems that would be most appropriate for the emerging competitive business environment. This report is a compilation of the findings from this Executive Meetings Project.		
<a href="#">SAND97-2926</a>	<b>Modeling of Battery Energy Storage in the National Energy Modeling System</b>	S. Swaminathan, W. T. Flynn, and R. K. Sen	Dec-97
	<b>Abstract:</b> The National Energy Modeling System (NEMS) developed by the U.S. Department of Energy's Energy Information Administration is a well-recognized model that is used to project the potential impact of new electric generation technologies. The NEMS model does not presently have the capability to model energy storage on the national grid. The scope of this study was to assess the feasibility of, and make recommendations for, the modeling of battery energy storage systems in the Electricity Market Module of the NEMS. Incorporating storage within the NEMS will allow the national benefits of storage technologies to be evaluated.		
<a href="#">SAND97-2700</a>	<b>Report on the Energy Storage Systems Program Executive Meetings Project</b>	C. Platt, P. Taylor, L. Charles, and P. C. Butler	Nov-97
	<b>Abstract:</b> Under the sponsorship of the U.S. Department of Energy (DOE) Office of Utility Technologies, the Energy Storage Systems Analysis and Development Department at Sandia National Laboratories conducted a series of dialogs with industry regarding the uses and value of storage in stationary applications. The dialogs consisted of meetings with industry executives in which Energy Storage Systems (ESS) Program management solicited input regarding expected changes in the electric utility industry and the long-term research and development in storage technologies and systems that would be most appropriate for the emerging competitive business environment. This report is a compilation of the findings from this Executive Meetings Project.		
<a href="#">SAND97-1136</a>	<b>Energy Storage Systems Program Report 1996</b>	P. C. Butler	Aug-97
	<b>Abstract:</b> Sandia National Laboratories, New Mexico, conducts the Energy Storage Systems program, which is sponsored by the U.S. Department of Energy's Office of Utility Technologies. The goal of this program is to assist industry in developing cost-effective energy storage systems as a resource option by 2000. Sandia is responsible for the engineering analyses, contracted development, and testing of energy storage systems for stationary applications. This report details the technical achievements realized during fiscal year 1996.		
<a href="#">(Contact Sandia Technical Library)</a>	<b>T&amp;D in Alaska: Like an Undeveloped Nation, in Electrical World</b>	P. Taylor, M. Demarest, and C. Butler	Aug-97
	<b>Abstract:</b> (Not available at this time)		
<a href="#">SAND97-1275/2</a>	<b>Battery Energy Storage Market Feasibility Study--Expanded Report</b>	A. Akhil and S. Kraft	Jul-97
	<b>Abstract:</b> Under the sponsorship of the U.S. Department of Energy's Office of Utility Technologies, the Energy Storage Systems Analysis and Development Department at Sandia National Laboratories (SNL) contracted Frost & Sullivan to conduct a market feasibility study of energy storage systems. The study was designed specifically to quantify the battery energy storage market for utility applications. This study was based on the SNL Opportunities Analysis performed earlier. Many of the groups surveyed, which included electricity providers, battery energy storage vendors, regulators, consultants, and technology advocates, viewed battery storage as an important technology to enable increased use of renewable energy and as a means to solve power quality and asset utilization issues. There are two versions of the document available, an expanded version (approximately 200 pages, SAND97-1275/2) and a short version (approximately 25 pages, SAND97-1275/1).		
<a href="#">SAND97-1275/1</a>	<b>Battery Energy Storage Market Feasibility Study</b>	A. Akhil and S. Kraft	Jul-97
	<b>Abstract:</b> Under the sponsorship of the Department of Energy's Office of Utility Technologies, the Energy Storage Systems Analysis and Development Department at Sandia National Laboratories (SNL) contracted Frost & Sullivan to conduct a market feasibility study of energy storage systems. The study was designed specifically to quantify the energy storage market for utility applications. This study was based on the SNL Opportunities Analysis performed earlier. Many of groups surveyed, which included electricity providers, battery energy storage vendors, regulators, consultants, and technology advocates, viewed energy storage as an important enabling technology to enable increased use of renewable energy and as a means to solve power quality and asset utilization issues. There are two versions of the document available, an expanded version (approximately 200 pages, SAND97-1275/2) and a short version (approximately 25 pages, SAND97-1275/1).		
<a href="#">(Contact Sandia Technical Library)</a>	<b>Battery Storage All But Eliminates Diesel Generator, in Electrical World</b>	M. Demarest, P. Taylor, D. Achenbach, and A. A. Akhil	Jun-97
	<b>Abstract:</b> (Not available at this time)		

<a href="#">SAND97-0443</a>	<b>Cost Analysis of Energy Storage Systems for Electric Utility Applications</b>	A. Akhil, R. K. Sen, and S. Swaminathan	Feb-97
	<b>Abstract:</b> Under the sponsorship of the Department of Energy, Office of Utility Technologies, the Energy Storage System Analysis and Development Department at Sandia National Laboratories (SNL) conducted a cost analysis of energy storage systems for electric utility applications. The scope of the study included the analysis of costs for existing and planned battery, SMES, and flywheel energy storage systems. The analysis also identified the potential for cost reduction of key components.		
<a href="#">SAND97-1618J</a>	<b>Energy and Power Characteristics of Lithium-ion Cells</b>	Ganesan Nagasubramanian, Rudolph G. Jungst	Jan-97
	<b>Abstract:</b> We describe below the electrochemical performance characteristics (including charge/discharge characteristics at different rates) of 18650 and prismatic lithium-ion cells at ambient and sub-ambient temperatures. Ragone plots of power and energy data for these cells are compared and indicate that at room temperature the -500 mAh prismatic lithium-ion cells exhibit higher specific power and power density than the 18650 cells. Over the temperature range from 35°C to -20°C, the cell impedance is almost constant for both cell types. These cells show very little voltage drop for current pulses up to 1 A. Keywords: Lithium-ion; Ragone data.		
<a href="#">(Contact Sandia Technical Library)</a>	<b>DOE's Battery Storage Program, in Power Quality Assurance Magazine, Vol. 8, No. 1, p. 16</b>	G. P. Corey and G. A. Buckingham	Jan-97
	<b>Abstract:</b> (Not available at this time)		
<a href="#">SAND96-2900</a>	<b>Photovoltaic Battery &amp; Charge Controller Market and Applications Survey: An Evaluation of the Photovoltaic System Market for 1995</b>	Robert Hammond, Jane F. Turpin, Garth P. Corey, Thomas D. Hund, Steve R. Harrington	Dec-96
	<b>Abstract:</b> Under the sponsorship of the Department of Energy, Office of Utility Technologies, the Battery Analysis and Evaluation Department and the Photovoltaic System Assistance Center of Sandia National Laboratories (SNL) initiated a U.S. industry-wide PV Energy Storage System Survey. Arizona State University (ASU) was contracted by SNL in June 1995 to conduct the survey. The survey included three separate segments tailored to: a) PV system integrators, b) battery manufacturers, and c) PV charge controller manufacturers. The overall purpose of the survey was to: a) quantify the market for batteries shipped with (or for) PV systems in 1995, b) quantify the PV market segments by battery type and application for PV batteries, c) characterize and quantify the charge controllers used in PV systems, d) <i>characterize</i> the operating environment for energy storage components in PV systems, and e) estimate the PV battery market for the year 2000. All three segments of the survey were mailed in January 1996. This report (discusses the purpose, methodology, results, and conclusions of the survey.		
<a href="#">(Contact Sandia Technical Library)</a>	<b>Lead-Acid Batteries in Systems to Improve Power Quality, Fifth European Lead Battery Conference, Barcelona, Spain</b>	P. C. Butler, P. Taylor, and W. Nerburn	Oct-96
	<b>Abstract:</b> (Not available at this time)		
<a href="#">(Contact Sandia Technical Library)</a>	<b>Energy Storage Solutions for Premium Power, in IEEE Aerospace and Electronics Systems, vol. 11, pp. 41-44</b>	G. P. Corey	Jun-96
	<b>Abstract:</b> (Not available at this time)		
<a href="#">SAND96-1062</a>	<b>Sodium/Sulfur Battery Engineering for Stationary Energy Storage—Final Report</b>	A. Koenig and J. Rasmussen	Apr-96
	<b>Abstract:</b> The use of modular systems to distribute power using batteries to store off-peak energy and a state-of-the-art power inverter is envisioned to offer important national benefits. A 4-year, cost-shared contract was performed by Silent Power, Inc., to design and develop a modular, 300-kVA/300-kWh system for utility and customer applications. Called Nas-PAc, this system uses advanced sodium/sulfur batteries and requires only about 20% of the space of a lead-acidbased system with a smaller energy content. Ten, 300-VDC, 40-kWh sodium/sulfur battery packs are accommodated behind a power conversion system (PCS) envelope with integrated digital control. The resulting design facilitates transportation, site selection, and deployment because the system is quiet and non-polluting, and can be located in proximity to the load. This report contains a detailed description of the design and supporting hardware development performed under this contract.		
<a href="#">SAND96-0532</a>	<b>Utility Battery Storage Systems Program Report for FY95</b>	Paul C. Butler	Mar-96
	<b>Abstract:</b> Sandia National Laboratories, New Mexico, conducts the Utility Battery Storage Systems Program, which is sponsored by the U.S. Department of Energy's Office of Utility Technologies. The goal of this program is to assist industry in developing cost-effective battery systems as a utility resource option by 2000. Sandia is responsible for the engineering analyses, contracted development, and testing of rechargeable batteries and systems for utility energy storage applications. This report details the technical achievements realized during fiscal year 1995.		

<a href="#">SAND95-2287J</a>	<b>Battery Technology Evaluation at Sandia National Laboratories</b> <i>Abstract:</i> (Not available at this time)	Paul C. Butler	Oct-95
<a href="#">SAND95-0420</a>	<b>Utility Battery Storage Systems Program Report for FY94</b> <i>Abstract:</i> Sandia National Laboratories, New Mexico, conducts the Utility Battery Storage Systems program, which is sponsored by the U. S. Department of Energy's Office of Energy Management. The goal of this program is to assist industry in developing cost-effective battery systems as a utility resource option by 2000. Sandia is responsible for the engineering analyses, contracted development, and testing of rechargeable batteries and systems for utility energy storage applications. This report details the technical achievements realized during fiscal year 1994.	Paul C. Butler	Mar-95
<a href="#">SAND93-930047j</a>	<b>"Sodium Beta Batteries," (Handbook of Batteries, Chapter 12, McGraw Hill)</b> <i>Abstract:</i> (Not available at this time)	J. W. Braithwaite and W. L. Auxer	Jan-95
<a href="#">SAND94-3105J</a>	<b>Spectroelectrochemical Studies on Metallophthalocyanines Adsorbed on Electron Surfaces</b> <i>Abstract:</i> Co(II)- and Fe(II)-phthalocyanines adsorbed on platinum and various carbon electrode surfaces have been studied by spectro-electrochemical techniques. The metallophthalocyanine (MPc) films were prepared on substrate electrodes by a drop-dry method after dissolving them in pyridine. While not much change in spectroscopic properties is observed for MPc's adsorbed at the platinum electrode, both the Soret and Q bands were significantly broadened when adsorbed on the carbon electrodes. Also, the metal-ligand charge transfer (MLCT) bands are observed from CoPc films adsorbed on carbon substrates even if they are not reduced. These observations lead to a conclusion that the MPc molecules not only undergo oligomerization but also interact strongly with carbon surfaces by perhaps sharing $\pi$ -electrons of carbon.	David T. Ingersoll, Narayan Doddapaneni, Su-Moon Park, Bertha Ortiz, Sun-Il Mho	Dec-94
<a href="#">SAND94-2605</a>	<b>Battery Energy Storage for Utility Applications: Phase I – Opportunities Analysis. Sandia National Laboratories</b> <i>Abstract:</i> One of the goals of the Utility Battery Storage Systems (UBS) Program is to characterize potential electric utility applications for battery energy storage and their economic benefit. The UBS program is conducted by Sandia National Laboratories and sponsored by the U.S. Department of Energy's Office of Energy Management. An initial analysis was performed to identify specific utility applications, to develop engineering requirements for each, to identify entry markets for specific battery technologies, and to assess national-level benefits for each application. Input was provided by representatives from utilities, battery and battery systems manufacturers, consultants, and UBS staff. The results of this study are presented in this report.	P. C. Butler	Oct-94
<a href="#">SAND94-2047</a>	<b>Zinc-air Technology: December 1993 Meeting Report</b> <i>Abstract:</i> A Zinc/Air Battery Review and Strategic Planning Meeting was held in 1993. One outcome of the meeting was recognition of the need for a report on the current status of the technology. This report contains contributions from many of the attendees at the above meeting and expresses their views on where the technology is today and what could/should be done to improve its performance.	Nancy H. Clark, K. Kinoshita	Oct-94
<a href="#">SAND93-3899</a>	<b>Utility Battery Storage Systems Program Report for FY93. Sandia National Laboratories</b> <i>Abstract:</i> Sandia National Laboratories, New Mexico, conducts the Utility Battery Storage Systems Program, which is sponsored by the U. S. Department of Energy's Office of Energy Management. In this capacity, Sandia is responsible for the engineering analyses, contract development, and testing of rechargeable batteries and systems for utility- energy-storage applications. This report details the technical achievements realized during fiscal year 1993.	P. C. Butler	Feb-94
<a href="#">SAND93-3900</a>	<b>Battery Energy Storage: A Preliminary Assessment of National Benefits (The Gateway Benefits Study). Sandia National Laboratories</b> <i>Abstract:</i> Preliminary estimates of national benefits from electric utility applications of battery energy storage through the year 2010 are presented along with a discussion of the particular applications studied. The estimates in this report were based on planning information reported to DOE by electric utilities across the United States. Future studies are planned to refine these estimates as more application-specific information becomes available.	A. A. Akhil, et al.	Dec-93



<a href="#">SAND93-2477</a>	<b>Battery Energy Storage and Superconducting Magnetic Energy Storage for Utility Applications: A Qualitative Analysis</b>	Abbas A. Akhil, Paul C. Butler, Thomas C. Bickel	Nov-93
	<i><b>Abstract:</b></i> This report was prepared at the request of the U.S. Department of Energy's Office of Energy Management for an objective comparison of the merits of battery energy storage with superconducting magnetic energy storage technology for utility applications. Conclusions are drawn regarding the best match of each technology with these utility application requirements. Staff from the Utility Battery Storage Systems Program and the Superconductivity Programs at Sandia National Laboratories contributed to this effort.		
<a href="#">SAND91-1818</a>	<b>Characteristics and Development Report for the MC4169 Double-Layer Capacitor Assembly</b>	Nancy H. Clark, Wes E. Baca	Sep-93
	<i><b>Abstract:</b></i> The MC4169 Double-Layer Capacitor Assembly was developed in response to a request from the B61 Systems organization to provide interim power for the B61 Common JTA Development. The project has been successfully completed, and Lot 1 has been built by MMSC/GEND. Development testing showed that this assembly met all design requirements. This report describes the design configuration, environmental testing, and aging, reliability, and safety studies done to ensure that the design requirements were met.		
<a href="#">SAND93-2023</a>	<b>Materials for Advanced Rechargeable Batteries</b>	Paul C. Butler, Sandra E. Klassen	Aug-93
	<i><b>Abstract:</b></i> (Not available at this time)		
<a href="#">SAND93-1754</a>	<b>Specific Systems Studies of Battery Energy for Electric Utilities</b>	A. A. Akhil, L. Lachenmeyer, S.J. Jabbour, and N. H. Clark	Aug-93
	<i><b>Abstract:</b></i> Sandia National Laboratories, New Mexico, conducts the Utility Battery Storage Systems Program, which is sponsored by the U.S. Department of Energy's Office of Energy Management. As a part of this program, four Utility-specific systems studies were conducted to identify potential battery energy storage applications within each utility network and estimate the related benefits. This report contains the results for these systems.		
<a href="#">SAND92-2272</a>	<b>Utility Battery Storage Systems Programs Report for FY92</b>	Paul C. Butler	Jan-93
	<i><b>Abstract:</b></i> Sandia National Laboratories, New Mexico conducts the Utility Battery Storage Systems Program, which is sponsored by the U.S. Department of Energy's Office of Energy Management. In this capacity, Sandia is responsible for the engineering analyses, contract development, and testing of rechargeable batteries for utility-energy-storage applications. This report details the technical achievements realized during fiscal year 1992.		
<a href="#">SAND91-2694</a>	<b>Utility Battery Exploratory Technology Development Program Report for FY-91</b>	Nicholas Magnai, Paul Butler, Abbas Akhil, Jeffrey Braithwaite, J. Freese, Nancy Clark	Dec-91
	<i><b>Abstract:</b></i> Sandia National Laboratories, Albuquerque, manages the Utility Battery Exploratory Technology Development Program, which is sponsored by the U.S. Department of Energy's Office of Energy Management. In this capacity, Sandia is responsible for the engineering analyses and development of rechargeable batteries for utility-energy-storage applications. This report details the technical achievements realized during fiscal year 1991.		
<a href="#">SAND91-0672</a>	<b>Exploratory Battery Technology Development Report for FY90</b>	Nicholas Magnani, Paul Butler, Abbas Akhil, Jeffrey Braithwaite, J. Freese, Stephen Lott	Apr-91
	<i><b>Abstract:</b></i> Sandia National Laboratories, Albuquerque, manages the Utility Battery Exploratory Technology Development Program, which is sponsored by the U.S. Department of Energy's Office of Energy Management. In this capacity, Sandia is responsible for the engineering analyses and development of advanced rechargeable batteries for stationary energy storage applications. This report details the technical achievements realized during fiscal year 1990.		

<a href="#">SAND89-3039</a>	<b>Exploratory Battery Technology Development and Testing Report for 1988</b>	Nicholas Magnani, Ronald Diegle, Jeffrey Braithwaite, D. Bush, Paul Butler, J. Freese, K. Grothaus, Kevin Murphy	Oct-89
	<i><b>Abstract:</b></i> Sandia National Laboratories, Albuquerque, has been designated as Lead Center for the Exploratory Battery Technology Development and Testing Project, which is sponsored by the U.S. Department of Energy's Office of Energy Storage and Distribution. In this capacity, Sandia is responsible for the engineering development of advanced rechargeable batteries for both mobile and stationary energy storage applications. This report details the technical achievements realized in pursuit of the Lead Center's goals during calendar year 1988.		
<a href="#">(Contact Sandia Technical Library)</a>	<b>Glossary of Testing Terminology for Rechargeable Batteries</b>	Paul C. Butler	Oct-88
	<i><b>Abstract:</b></i> (Not available at this time)		
<a href="#">(Contact Sandia Technical Library)</a>	<b>Exploratory Battery Technology Development and Testing Report for 1987</b>	Nicholas Magnani, Ronald Diegle, Jeffrey Braithwaite, D. Bush, Paul Butler, J. Freese, K. Grothaus, Kevin Murphy	Aug-88
	<i><b>Abstract:</b></i> (Not available at this time)		
<a href="#">(Contact Sandia Technical Library)</a>	<b>Exploratory Battery Technology Development and Testing Report for 1986</b>	Nicholas Magnani, Robert Clark, Jeffrey Braithwaite, D. Bush, Paul Butler, J. Freese, K. Grothaus, Kevin Murphy, Paul Shoemaker	Feb-88
	<i><b>Abstract:</b></i> (Not available at this time)		
<a href="#">(Contact Sandia Technical Library)</a>	<b>Exploratory Battery Technology Development and Testing Report for 1985</b>	Nicholas Magnani, Robert Clark, Jeffrey Braithwaite, D. Bush, Paul Butler, J. Freese, K. Grothaus, Kevin Murphy, Paul Shoemaker	Jun-87
	<i><b>Abstract:</b></i> (Not available at this time)		